

Mapping the Road to Recovery: Integrated Water Quality and Biological Monitoring of Onondaga Lake, New York

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Biographical Sketch of Authors

Elizabeth Moran is President of EcoLogic LLC a small environmental consulting firm located in Cazenovia New York. She earned her Master of Science and Doctor of Philosophy degrees at Cornell University in the field of Aquatic Sciences. Dr. Moran has more than 20 years of experience in limnology and water quality. She has served as technical lead on a number of watershed projects and has worked with multi-disciplinary teams of planners, engineers, and scientists to define the interrelationships between land use, point and nonpoint sources of pollution, water quality, and ecological integrity of surface waters.

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Joseph J. Mastriano is Operations Manager at the Onondaga County Department of Water Environment Protection where he has worked for the last 24 years. Mr. Mastriano leads the Engineering and Laboratory Services Division which provides a diverse range of engineering and technical services. His division oversees numerous programs and functions including Industrial Wastewater Pretreatment, Pollution Prevention, and the Onondaga Lake Ambient Water Quality Monitoring Program. A major focus of Mr. Mastriano's responsibility is compliance and environmental protection.

Abstract

Since 1970, Onondaga County Department of Water Environment Protection has monitored water quality conditions in Onondaga Lake and its tributary streams. The extensive database developed from the long-term monitoring program has directed attention to the need for improved wastewater collection and treatment in order to bring the waters into compliance with state and federal standards. In 1998 a court order required the County to implement major improvements to the wastewater infrastructure. The court also ordered the County to document response of affected water resources through a comprehensive monitoring program that builds on the historical water quality data but expands to include elements of ecological integrity. The monitoring program includes multiple elements to assess progress towards resolution of the habitat and contamination issues affecting restoration of the biotic community; these are critical issues with respect to attainment of the designated use of the resource for water contact recreation and fish propagation. Major projects are now underway to mitigate combined sewer overflows and improve the level of wastewater treatment. Water quality improvements are already evident in Onondaga Lake and throughout the watershed. The County must integrate the findings of the biological program with results of the water quality monitoring program in order to assess the effectiveness of the control measures and the need for additional controls. As conditions improve, the community of plants and animals is expected to shift to a more diverse assemblage less tolerant of polluted conditions. Biological indicators are therefore important elements of program design.

Introduction and Regulatory Context

Onondaga County Department of Water Environment Protection is responsible for designing and implementing a comprehensive monitoring program of Onondaga Lake, the lake tributaries, and portions of the Seneca River. The County's monitoring program, called the Ambient Monitoring Program (AMP), is designed to provide data and information regarding the effectiveness of a series of improvements to the County's wastewater collection and treatment system. Effectiveness is measured in terms of progress on two fronts: (1) compliance with water quality standards and guidance values and (2) restoration of a balanced ecological community of plants and animals.

Specific requirements of the AMP were developed in consultation with New York State Department of Environmental Conservation (NYSDEC), the Environmental Protection Agency (EPA) and Atlantic States Legal Foundation (ASLF). The AMP, which represents a modification and expansion of Onondaga County's water quality monitoring program in place since 1970, was implemented in August 1998. Modifications were made to focus the monitoring program on a series of hypotheses related to the effectiveness of the County's improvements to the wastewater collection and treatment system.

The AMP is one of the elements of an Amended Consent Judgment (ACJ) executed in January 1998. The ACJ specifies a series of actions and improvements that the County is required to undertake to improve and expand their infrastructure for wastewater collection and treatment. A detailed timetable for compliance is included.

The focus of the ACJ is the County's wastewater treatment plant and network of combined sewers that flow into Onondaga Lake. Onondaga County operates a wastewater treatment plant (the Metropolitan Syracuse Wastewater Treatment Plant, commonly referred to as Metro) that discharges to Onondaga Lake. The Metro facility was designed to provide advanced secondary treatment for biochemical oxygen demanding-material (BOD) and phosphorus removal for sewage flows of up to 120 mgd. Discharge to Onondaga Lake is through a surface outfall. Flows between 120 mgd and 220 mgd undergo primary treatment and chlorination prior to discharge to Onondaga Lake via a separate outfall. However, as stipulated in the ACJ, the discharge of treated wastewater causes or contributes to violations of ambient water quality standards in Onondaga Lake. The County is required to design, test and construct modifications and additions to the Metro facility to meet effluent limits designed to bring the lake into compliance with state and federal requirements. Modifications and additions are under construction to enable year-round nitrification of ammonia and filtration for phosphorus removal. The ACJ includes language requiring the County to modify the Metro discharge so that compliance with ambient water quality standards in the Lake is achieved, even if diversion of Metro effluent to the Seneca River is necessary to achieve these standards. The decision whether additional measures are required to bring the lake into compliance is scheduled for the year 2009. Engineering alternatives that fully comply with water quality standards must be implemented by December 1, 2012.

Combined sewer overflows (CSOs) discharge to three of the lake's tributary streams. For the combined sewers, the ACJ requires the County to design, construct, maintain, and modify and/or supplement as necessary, a CSO control and upgrade program. The program must meet requirements established in State and federal policy and guidance. A remedial program to separate some sewers and treat the remaining combined overflows is underway.

Improvements to Metro and the CSOs are being implemented in a phased program, with final completion dates in the year 2012. Loading reductions of wastewater related pollutants (ammonia, phosphorus, solids, floatables and bacteria) will be accomplished as discrete step improvements, not gradual reductions in loading. The ACJ includes specific milestone dates for assessment of progress and evaluation of the need for additional treatment or controls.

The County's Ambient Monitoring Program is designed to provide the data and information needed to support these important decisions regarding the effectiveness of the control measures and the need for additional controls. Both annual elements, designed to recur each year to evaluate compliance and establish trends, and special

elements, timed to follow the construction-related milestones are included in the AMP. Specific objectives of the comprehensive monitoring effort may be summarized as follows:

1. Quantify external loading of phosphorus, nitrogen, suspended solids, indicator bacteria, and salts. Design program to include stations upstream and downstream of potential sources in the watershed.
2. Assess the tributaries' physical habitat and macroinvertebrate community.
3. Gather data on an adequate temporal and spatial scale to assess compliance with ambient water quality standards.
4. Evaluate the lake's response to reductions in external loading achieved by the planned improvements to Metro and the CSOs.
5. Expand the chemical monitoring program to include other indices of ecological integrity: biological data, contaminant burden, and physical habitat.
6. Through interaction with New York State Department of Environmental Conservation and other reviewers, coordinate data collection and analysis to provide data at an adequate spatial and temporal scale to use in existing or revised lake models.
7. Define ambient water quality conditions in the Seneca River between Cross Lake and Three Rivers.
8. Evaluate and quantify the assimilative capacity of the Seneca River and quantify effects of zebra mussels.

Because the AMP will continue over an extended time period, the parties designing and approving the program consider flexibility to be an important consideration. Monitoring results are continually reviewed by engineers and scientists associated with NYSDEC, EPA, and other interested parties. The County has convened a Technical Advisory Committee to provide expert advice and oversight.

Environmental Setting

Onondaga Lake is located immediately northwest of the City of Syracuse in Onondaga County, New York, USA (43° 6' 54" N, 76° 14' 34" W). The outlet of Onondaga Lake flows into the Seneca River, which joins with the Oswego River and flows north and east into Lake Ontario.

The Onondaga Lake drainage basin encompasses approximately 642 km², and with the exception of 2 km² in Cortland County, lies almost entirely in Onondaga County. The drainage basin includes six natural subbasins: Nine Mile Creek, Harbor Brook, Onondaga Creek, Ley Creek, Bloody Brook, and Saw Mill Creek.

The climate of the Onondaga Lake basin is continental humid and is strongly influenced by proximity to Lake Ontario and the presence of the Appalachian upland in the southern part of the drainage basin. Lake Ontario moderates the temperature extremes. The summer months are drier on average, but high year-to-year variation is typical. In 2001, the annual precipitation was 34.3 inches. This is well below the long-term average of 39 inches for the period of record and reflective of continued below normal precipitation levels in the Northeast.

Onondaga Lake is relatively small, with 7.6 km maximum length, 2 km maximum width, 11.7 km² surface area, 131 x 10⁶ m³ volume, 10.9 m mean depth, and 19.5 m maximum depth. The lake has a very short water residence time (averaging just over 3 months) due to its small size and large watershed. The Onondaga Lake shoreline is very regular, with few embayments. More than 75 percent of the shoreline is owned by Onondaga County and is maintained as part of a popular park and trail system. The lakeside park is currently used for recreation (hiking,

biking, jogging, roller-blading, etc.), fishing, and cultural entertainment. The lake is used for secondary water contact recreation such as boating and water skiing.

Fishing was prohibited in the lake in 1972 due to mercury contamination. The prohibition was lifted in 1986 and modified into a catch and release fishery, i.e. recreational fishing was permitted but possession of lake fishes was not. In 1999 the New York State Department of Health revised its advisory regarding consumption of gamefish from Onondaga Lake. The current recommendation is to eat no walleye from Onondaga Lake, and restrict consumption of all other species to no more than one meal per month. The fish advisory continues to be based on mercury levels in fish flesh. As in all New York waters with health advisories, the Health Department advises that women of childbearing age, infants, and children under the age of 15 eat no fish from these waters.

Elements of the Current Program

The AMP has developed into a comprehensive program that includes physical, chemical, and biological monitoring of Onondaga Lake, its tributary streams, and the Seneca River (Table 1). In addition to the water quality monitoring efforts, the AMP includes elements designed to assess progress towards resolution of the habitat and contamination issues affecting restoration of the biotic community. These are critical issues with respect to attainment of the designated use of the resource for water contact recreation and fish propagation.

As water quality conditions improve, the community of plants and animals living in Onondaga Lake and the watershed streams is expected to shift to a more diverse assemblage less tolerant of polluted conditions. This hypothesis underlies the approach of using indicator organisms to infer water quality conditions. Biological surveys are used to directly assess the status of a waterbody relative to the primary goal of the Clean Water Act. The biological community integrates the effects of different pollutant stressors and thus provides a holistic measure of their aggregate effect.

Framework for Integration

Onondaga County and the other parties will evaluate the results of the AMP in order to assess the effectiveness of the control measures for Metro and the CSOs. These data sets are meant to provide the data and information needed to support regulatory decisions regarding the need for wastewater diversion from Onondaga Lake..

The framework for organizing the massive amounts of data (both water quality and biological) collected through the AMP is the restoration goals summary, a living document designed to help focus data analysis and interpretation of the water quality and biological surveys. Summaries are organized in terms of testable hypotheses so that data analysis and interpretation can be targeted to address the questions of greatest concern. An example of the restoration goals summary developed for the issue of ammonia nitrogen levels is included as Table 2. The restoration goals summary includes a worksheet for each of the monitored parameters. Note that the evaluation criteria for ammonia nitrogen are relatively straightforward: is there compliance with ambient water quality standards. Interpreting the biological monitoring programs is more complex, as the focus is on indicators of status and trends in the ecosystem rather than simple compliance with standards. Table 3 summarizes the modeling framework for two interrelated elements of the biological monitoring program: phytoplankton and zooplankton. Note the reliance on multiple metrics such as relative abundance of taxa and size distribution to serve as indicators of the health of the ecosystem.

In addition to the individual worksheets, there is a need to integrate data collected through the AMP to provide an overall assessment of the state of the ecosystem and how it is changing in response to alterations in external loading. Complicating the analysis are factors such as the recent invasion of the system by the zebra mussel. Data integration is based on a conceptual model of how the lake and watershed function (Figure 1). The conceptual model provides a tool for reviewing and interpreting data. It is also a valuable means to determine the adequacy of the monitoring program itself and determine whether the appropriate questions are being asked of the ecosystem and the data set.

Conclusions

The Onondaga County Department of Water Environment Protection has committed to a 15-year program of monitoring and analysis of the Onondaga Lake ecosystem and a segment of the Seneca River. The AMP is a dynamic program designed to provide the County and the regulatory agencies the data and information required to make significant decisions regarding the level of treatment and ultimate discharge location of treated wastewater and combined sewer overflows. The focus is on ecological integrity: progress towards use attainment and ecological restoration of the system includes a multi-metric examination of physical and habitat setting, water chemistry, and the structure and function of the food web.

Challenges remain, particularly related to the interactions and effects of factors such as industrial residuals that are not directly related to the wastewater and CSO discharges. The multiparameter approach was designed to provide multiple lines of information regarding the ecological health of the lake and river system.

TABLE 1
Summary of Onondaga County's Ambient Monitoring Program

Issue	Program	Comments
External Loading	Monitor streams and point sources for flow, nutrients, solids, indicator bacteria, metals, salts.	Regular (biweekly) sampling complemented with storm and high flow event monitoring.
Lake water quality: compliance and trends	<u>Physical characteristics</u> : temperature, light penetration, turbidity. <u>Chemical characteristics</u> : nutrients, salts, dissolved oxygen, ammonia, pH, metals. <u>Biological characteristics</u> : chlorophyll a, phytoplankton zooplankton, indicator bacteria. <i>Additional biological parameters are summarized below.</i>	Profiles through water column. Water quality monitoring buoy at deepest location (profile sampling). Biweekly monitoring March – December. Indicator bacteria monitoring to assess suitability for water contact recreation.
Tributary water quality, biota, and habitat conditions	<u>Water quality</u> Annual program for flow, nutrients, solids, bacteria, metals, salts. <u>Habitat and Biota</u> : Every 2 years: monitor stream macroinvertebrate community. Stream mapping based on NRCS Visual Assessment Protocol	Focus is on the CSO-affected tributaries. Additional effort is placed on partitioning point and nonpoint sources of phosphorus from urban areas.
Onondaga Lake Biological Community	<u>Fish community</u> : annual assessment of nests, larval fishes, juveniles, adults using multiple sampling gears and techniques. <u>Macrophytes</u> : annual aerial photography for percent cover of littoral zone (limited ground truthing) <u>Littoral macroinvertebrates</u> : every 5 years, community structure and abundance. <u>Zebra mussels</u> : habitat mapping and sampling at reference locations.	Focus on metrics of community structure, food web dynamics. Biological sampling of littoral zone complemented with sampling of sediment texture.
Seneca River: Compliance, trends, assimilative capacity, zebra mussel dynamics	<u>Water quality</u> (dissolved oxygen, nutrients, oxygen demand, salts, temperature, chlorophyll-a, etc.). <u>Zebra mussels</u> : habitat mapping and sampling at reference locations. River flow and discharge of point sources.	Sampling concentrated at low flow conditions. Mathematical model under development to quantify waste load assimilative capacity and support TMDL allocation.

TABLE 2

Example of Restoration Goal Summary for Ammonia Nitrogen

Restoration Goal	
Compliance with the applicable ambient water quality standard in the upper waters and/or removal of ammonia toxicity as an impairment to designated best use for survival and propagation of a warmwater fish community.	
Baseline Conditions	
Major Sources	Metro effluent. Mean contribution: 90.4 % (S.D. 3.4)
Upper waters concentration	Annual mean 1988-2000: 1.7 mg/l (S.D. 0.62) 2000: 0.58 mg/l Decreasing trend through 2000 (p=0.074)
Compliance with NYS Ambient Water Quality Standard in Upper Waters	Days of violation (1992-2000 mean 170 days S.D. 73) 2000: 28 days <i>sampling period approx. 280 days</i>
Factors Affecting Compliance	Hydrology, Metro performance, pH and temperature of receiving water
Planned Load Reductions (1998 – 2012)	
Metro SPDES Permit Requirement <i>NOTE: The County is currently projected to meet the Stage 3 limits by May 1, 2004, 8 years ahead of schedule.</i>	Stage 1 Limit: Cap on Loading (effective Jan. 1998) <ul style="list-style-type: none"> July 1 – Sept. 30: 8700 ppd (as NH₃) Oct. 1 – June 30: 13,100 ppd (as NH₃) Stage 2 (effective May 1, 2004): <ul style="list-style-type: none"> June 1 – Oct. 31: 2.0 mg/l (as NH₃) Nov. 1 – May 31: 4.0 mg/l (as NH₃) Stage 3: (effective Dec. 2012) <ul style="list-style-type: none"> June 1 – Oct. 31: 1.2 mg/l (as NH₃) Nov. 1 – May 31: 2.4 mg/l (as NH₃) Or as required by a revised TMDL (anticipated in 2009)
Monitoring and Assessment Program	
Hypothesis to be tested (H ₀)	Implementation of load reductions will have no impact on compliance with the ambient water quality standard.
Loading estimates	<ul style="list-style-type: none"> Biweekly tributary monitoring, supplemented with samples collected during high flow conditions Daily measurements of Metro effluent
Lake Monitoring	<ul style="list-style-type: none"> Biweekly profiles in Lake, April –Nov Winter sampling as weather allows
Related Biological Monitoring	<ul style="list-style-type: none"> Assessment of fish community Annual zooplankton monitoring
Tools for Decision Making	
Models	<ul style="list-style-type: none"> Nitrogen model dated 4/1/93 calibrated to high loading conditions <i>NYSDEC to verify the ability of this model to simulate lake conditions following implementation of Phase 2 limits at Metro.</i>
TMDL Allocations	NYSDEC Phase I TMDL 8/27/97 Phase II TMDL by January 2009
Ambient Water Quality Criteria and Standards	NYSDEC to review and revise its ammonia standards in the near future. Current standards are more stringent than the federal criteria.

TABLE 3

Example of Restoration Goal Summary for Biological Parameters

Restoration Goal: Phytoplankton	
Abundance and composition of the algal community typical of a eutrophic lake in the same geologic and climatic setting. Decreased importance of cyanobacteria (blue-green algae).	
Baseline Conditions	
Biomass and Community composition	1968 – 1996 data set. Abundance of major groups 1997 – present data set. Biomass and biovolume
Forcing functions	Nutrients, light, temperature, grazing pressure
<i>Monitoring and Assessment Program</i>	
Lake Monitoring	Biweekly sampling events: <ul style="list-style-type: none"> • Phytoplankton abundance (number per liter) • Biomass (µg/l) • Composition of the algal community (7 major groups) • Cell size divisions (nannoplankton and netplankton) Metrics to track over time: <ul style="list-style-type: none"> • Percent of major taxa • Blue-green algae dynamics and shifts in N:P ratio of lake water • Number of taxa (1995 and later) • Diversity (1995 and later) • Percent dominance (1995 and later)

Restoration Goal: Zooplankton	
Abundance and composition of the zooplankton community are comparable to reference eutrophic lake in same geologic and climatic setting.	
Baseline Conditions	
Biomass and Community composition	Density (numbers per ml for major types) Qualitative discussion in annual reports Since 1995, biomass of organisms
Forcing functions	Food supply (algal abundance) grazing pressure (fish community structure), water quality (ammonia, chlorides, extent of aerobic habitat)
<i>Monitoring and Assessment Program</i>	
Lake Monitoring	<ul style="list-style-type: none"> • Biweekly monitoring for density (organisms per ml) and biomass (µg/l), March – November • Average size in spring (June 1 – 15) and fall (Sept. 1 – 15) • Relative biomass of major caldoceran types • Relative biomass of major copepod types • Number of crustacean taxa (1995 on)

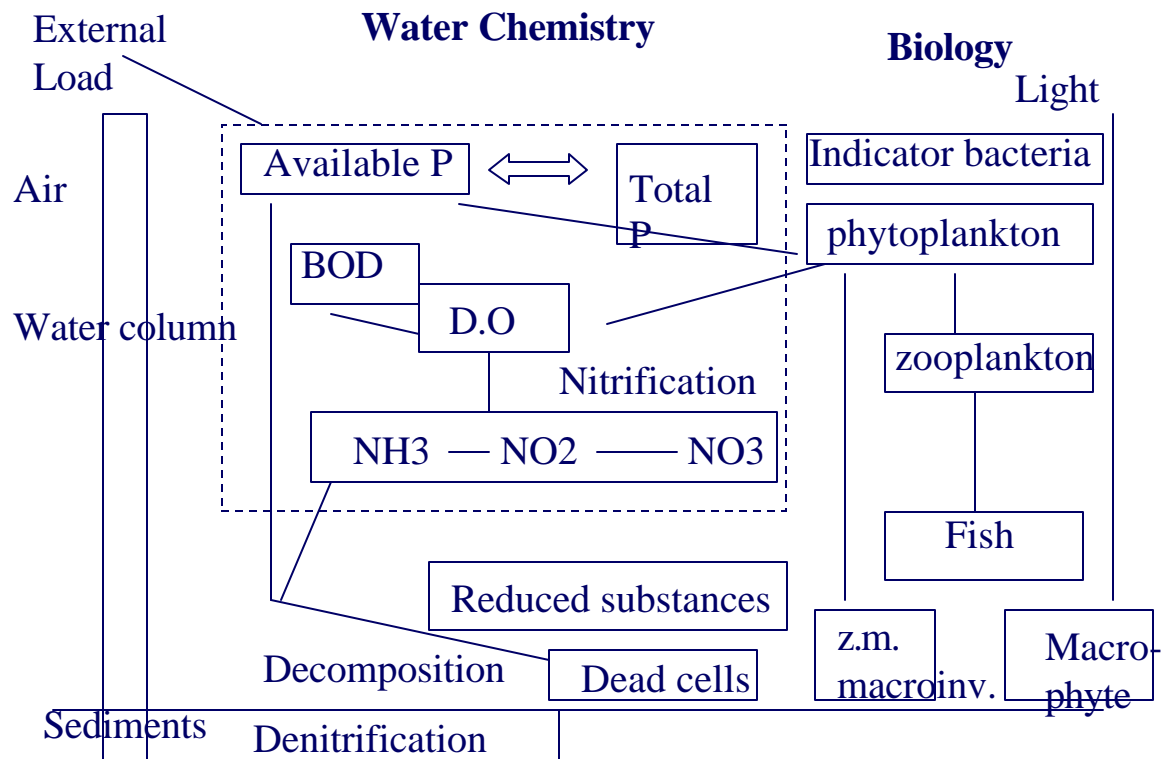


Figure 1. Conceptual model of Onondaga Lake ecosystem used to guide design of Ambient Monitoring Program (AMP) and interpretation of multiple data metrics.